The spin and woolen films effects on the movement trajectory of the tennis ball

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I. Introduction

The spin has a great effect on the tennis trajectory and it plays an important role in the games, this phenomenon is called the Magnus effect. In this study we use image analysis method to measure the discrepancy of movement trajectories of between the no-hairy (without woolen films) and normal tennis (with woolen films) balls, and moreover to calculate the drag force and the Magnus force in several spin configurations. Finally, we found the surface material has a lot to do with the drag force, but it doesn't significant influence on the Magnus force.

II. Experimental setup

To observe the movement trajectory of the tennis ball, we made a machine to serve the tennis ball with the constant velocity, and its spin frequency can be adjusted. This serve machine contains two wheels which connected with electric motors. We can make the tennis ball in different initial conditions by turning on or turning off the two wheels. We measured the velocity and the rotating speed of tennis ball with the high speed camera. The shooting setting of the high speed camera is 600 frame per second (FPS). We used the green pigments to produce the no-hairy tennis ball in order to reduce the function of the woolen films.

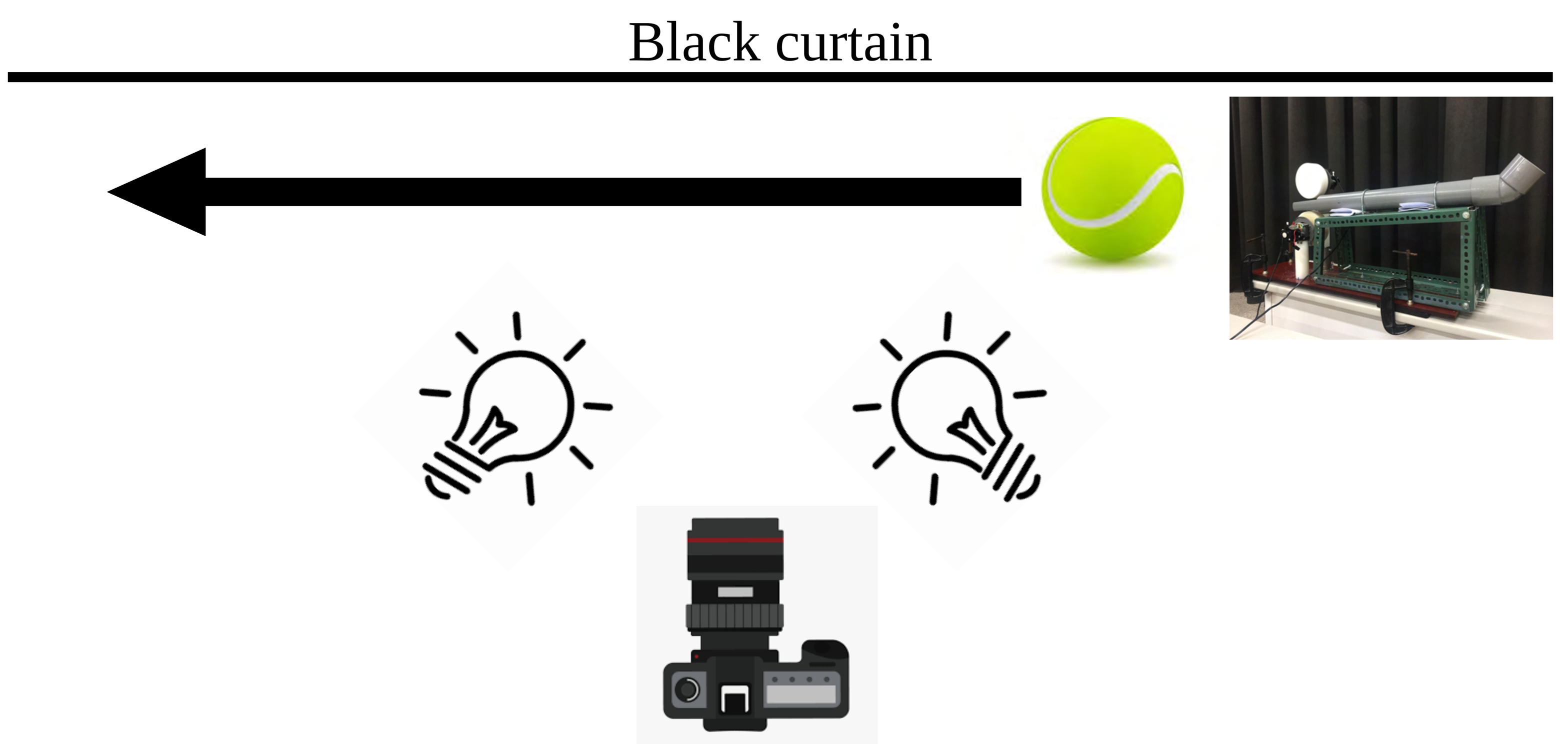


Figure 1. The schematic drawing of the experimental setup

III. Principle

When the tennis ball is fling, it sustains the drag force opposite to its flight direction. The drag force is caused by the air resistance. The drag force is proportional to the velocity of the tennis ball:

$$\boldsymbol{F_D} = -C_D \boldsymbol{v} \quad (1)$$

Where $\boldsymbol{F_D}$ is the drag force, v is the velocity of the tennis ball and C_D is the constant of the drag force which concludes the material of the surface, the density of the air, the cross-sectional area of the ball and so on.

When the tennis ball rotates, the Magnus force will be produced, and the direction of the Magnus force will depend on the flight direction and the spin axes. The Magnus force cab be presented as:

$$\boldsymbol{F_M} = C_M(\boldsymbol{\omega} \times \boldsymbol{v}) \quad (2)$$

where $\boldsymbol{F_M}$ is the Magnus force, $\boldsymbol{\omega}$ is the angular velocity of the tennis ball, $\boldsymbol{v}$ is the velocity of the tennis ball, and C_M is the constant of the Magnus force which also concludes the material of the surface, the density of the air, the cross- sectional area of the ball and so on.

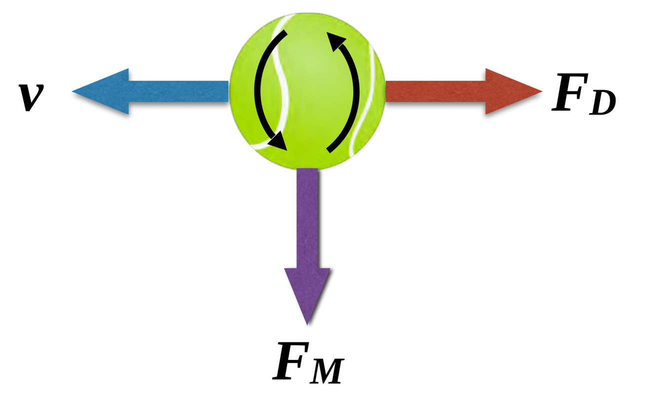


Figure 2. The schematic of topspin

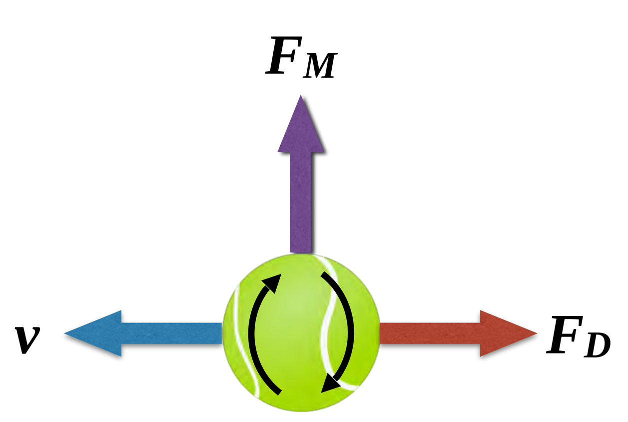
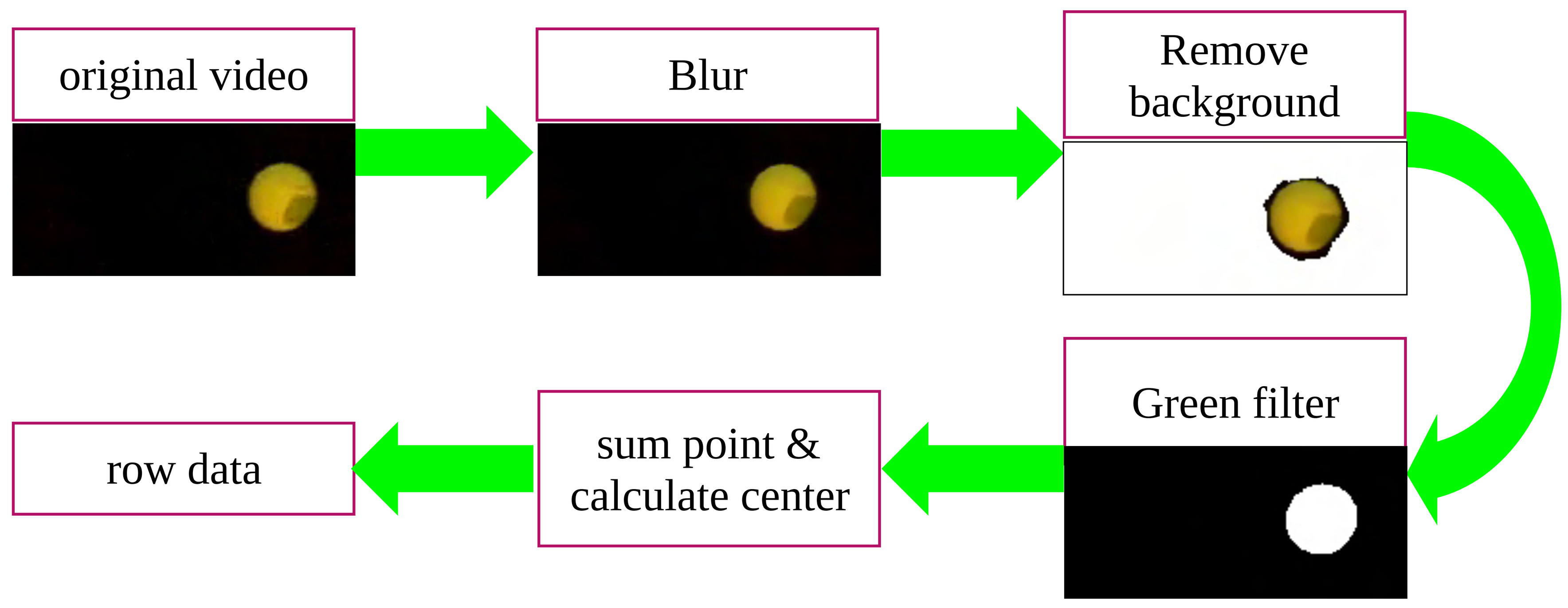


Figure 3. The schematic of backspin

IV. Image analysis



V. Data analysis

In this experiment, we assumed the time of the whole film is extreme short, and we fitted the graph of the position to the time in the y-direction with the equation of the parabola:

$$y = at^2 + bt + c \quad (3)$$

where $\boldsymbol{a}$ is the half of the acceleration and figure 4 is the result.

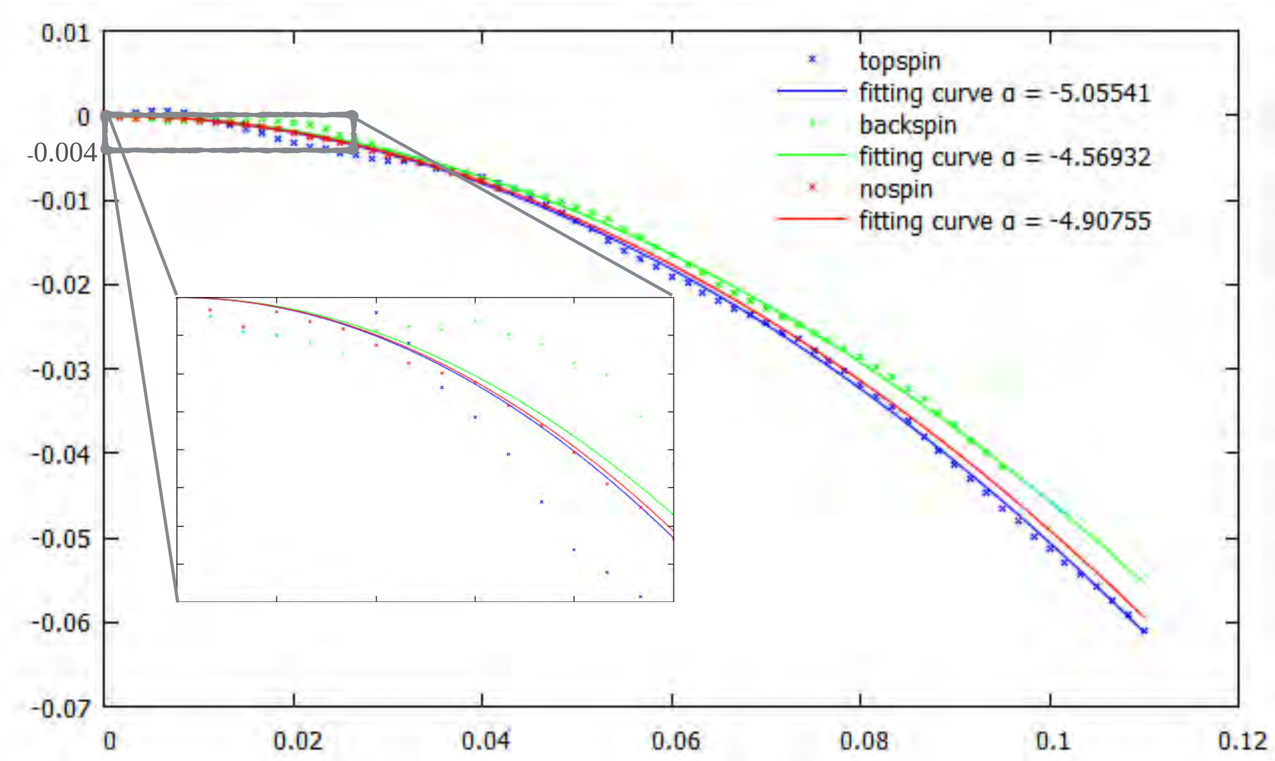


Figure 4. The result of the fitting with the equation of the parabola and the data has revised, so they can pass the same origin.

We found the average point we calculate is not on the rotational axis of the tennis ball in the film, so we analyzed the data of the velocity to the time with the fast Fourier transform (FFT), and the result shows there is a strong signal when the frequency is ***30 Hz***. It represents the angular frequency of the tennis ball is ***30 Hz***

VI. Results

Figure 5 shows that the normal ball sustains drag force much higher than the no-hairy ball in all spin configurations.

Figure 6 shows that woolen films do not affect the constant of Magnus force as well as the constant of drag force in topspin and backspin conditions.

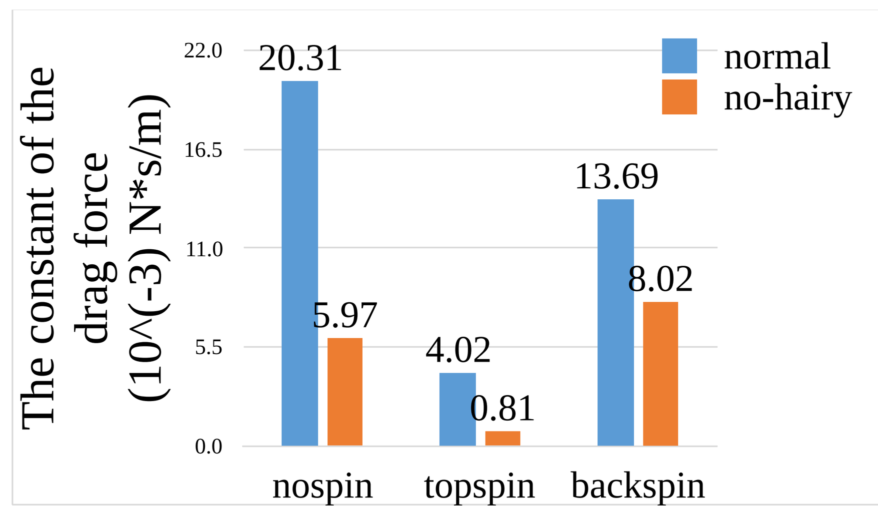


Figure 5. The constant of the drag force of the normal and the no-hairy

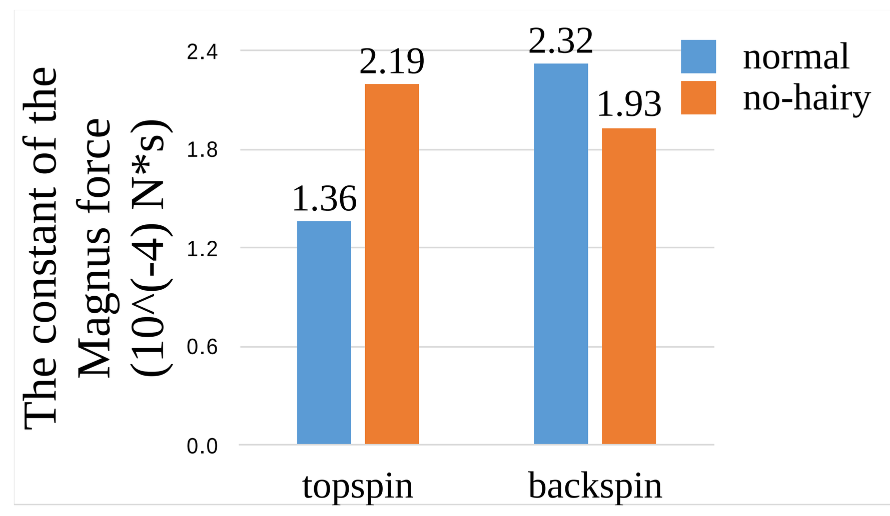


Figure 6. The constant of the Magnus force of the normal and the no-hairy

VII. Conclusion

1. The drag force of the normal ball is greater than one of the no-hairy ball in the same initial condition.
2. The surface material of the tennis ball affects the constants of Magnus force and drag force, but just a little for Magnus force.
3. The trajectory of tennis ball is affected by the Magnus force and the drag force, but the drag force is the main factor.
4. The woolen films on the tennis ball can reduce the velocity of the tennis ball.

VIII. Reference

[1] Cross, R. and C. Lindsey. Tennis Ball Trajectories-Aerodynamic Drag and Lift in Tennis Shots. Transaction of the Sports engineering 17(2): 89-96, 2013.